13/prts

9/prts

SPECIFICATION

Optical Pickup Device

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Technical Field

The present invention relates generally to optical pickup devices and particularly to those used in magneto-optical disk reproduction apparatuses.

Background Art

In recent years there has been developed a magneto-optical disk reproduction apparatus capable of repeatedly recording and reproducing images, documents and other similar data and it is considered important to make an optical pickup device smaller because it is the magneto-optical disk reproduction apparatus.

A magneto-optical pickup device intended to be small is disclosed in Japanese Patent Laying-Open No. 8-329544. With reference to Figs. 11 and 12, a first conventional magneto-optical pickup device includes an optical module 35, an optically transparent substrate 41 arranged on optical module 35, a polarizing prism 43 arranged on optically transparent substrate 41, and formed of a prism having a triangular cross section and a prism having a parallelogramic cross section bonded together, and thus having a trapezoidal cross section, and an objective lens 45 arranged above polarizing prism 43 and serving as a condensing element. Optical module 35 is internally provided with a substrate 36 and on substrate 36 are formed a laser diode 37 and photodiodes 38-40. Photodiodes 38 and 39 are divided into six photodiodes 38a-38f and six photodiodes 39a-39f, respectively, as shown in Fig. 12. Furthermore, photodiode 40 is divided in two photodiodes 40a and 40b. Optically transparent substrate 41 has a surface facing laser diode 37 with a hologram diffraction element 42 formed therein.

A joint plain 43a of the triangular and parallelogramic prisms of polarizing prism 43 is a plane dividing light into polarized beams and it is adapted to have a transmittance of 70% and a reflectance of 30% for light emitted from laser diode 37 (P polarized light) and a transmittance of 100%

for S polarized light.

On photodiode 40 is arranged an analyzer prism 44 formed of a prism having a triangular cross section and a prism having a paralellogramic cross section that are bonded together and provide a trapezoidal cross section. The two prisms have a joint plane 44a, which is a plane dividing light into polarized beams and it adapted to have a transmittance of 100% for P polarized light and a reflectance of 100% for S polarized light. Analyzer prism 44 has joint plane 44a over photodiode 40a and a reflection plane 44b over photodiode 40b.

The magneto-optical pickup device as described above generally operates, as follows: laser diode 37 emits P polarized light which in turn moves past optically transparent substrate 41 at hologram diffraction element 42 and it is then incident on polarizing prism 43 at a plane 43a dividing light into polarized beams. Seventy percent of the incident, P polarized light moves past plane 43a and it is then condensed by objective lens 45 on a magneto-optical recording medium 12. The condensed light, on magneto-optical recording medium 12, has a plane of polarization rotated by 0.5° by a magnetic signal recorded on the medium and also obtains an S polarized component corresponding to a magneto-optical signal component and it is reflected and moves past objective lens 45 and thus returns to plane 43a. Plane 43a passes 70% of the P polarized component and reflects 30% of the P polarized component and 100% of the S polarized component. The reflected light is further reflected by reflection plane 43b and it moves past optically transparent substrate 41, enters optical module 35 and is incident on analyzer prism 44 at a plane 44a dividing light into polarized beams. The light incident on plane 44a has a P polarized component moving past the plane and thus incident on photodiode 40a, and an S polarized component reflected by the plane and further reflected by reflection plane 44b and then incident on photodiode 40b.

Thus photodiodes 40a and 40b provide signals. If the signals are represented by the respective reference characters, a magneto-optical signal RF is represented by the following equation:

$$RF = 40a - 40b \qquad \text{... (1).}$$

The light moving past plane 43a is incident on hologram diffraction element 42 and diffracted at an angle of diffraction of 5° to 20°, and a positive, first-order diffracted beam of light is incident on photodiode 38 and a negative, first-order diffracted beam of light is incident on photodiode 39. Hologram diffraction element 42 has an effect of a lens and the positive, first-order diffracted beam focuses at a point closer to hologram diffraction element 42 than photodiode 38 and the negative, first-order diffracted beam focuses at a point farther than photodiode 39. When the magneto-optical pickup device and magneto-optical recording medium 12 focus, photodiodes 38 and 39 have thereon their respective spots of light having the same diameter and a focus error signal FE can be represented by the following equation:

$$FE = \{ (38a+38c+38d+38f) + (39b+39e) \} - \{ (38b+38e) + (39a + 39c+39d+39f) \} \quad \ldots (2).$$

Furthermore, if the magneto-optical pickup device is arranged such that a line dividing photodiodes 38a-38c and 38d-38f and a line dividing photodiodes 39a-39c and 39d-39f are parallel to a direction of an information track of magneto-optical recording medium 12, a tracking error signal TE can be represented by the following equation:

$$TE = \{ (38a+38b+38c+) + (39a+39b+39c) \} - \{ (38d+38e+38f) + (39d + 39e+39f) \} \quad \ldots (3).$$

Since polarization prism 43 is provided integral to optical module 35 and has different reflectances and transmittances for P polarized light and S polarized light, the magneto-optical pickup device can be miniaturized and light can also be utilized more efficiently to ensure a sufficient signal to noise (S/N) ratio of a magneto-optical signal.

Japanese Patent Laying-Open No. 8-329544 also discloses a magneto-optical pickup device, as described below:

With reference to Figs. 13 and 14, the second conventional magneto-optical pickup device is distinguished from the first magneto-optical pickup device in that polarizing prism 43 is formed of three triangular prisms having a triangular cross section and a polarizing hologram 54 arranged between the three triangular prisms, photodiodes 38 and 39 arranged on

opposite sides of hologram diffraction element 42 and laser diode 37 are removed, and that photodiodes 55, 56 and 57 are positioned to receive 0th-, first-, and negative first-order beams, respectively, passed from polarizing hologram 54.

Polarizing hologram 54 is formed of lithium niobate and it serves to separate light incident thereon into two linearly polarized components orthogonal to each other and output one linearly polarized component as a 0th-order beam of light and the other component as positive and negative, first-order beams of light.

Furthermore, polarizing hologram 54 has an effect of a lens allowing different focal points of the positive and negative, first-order diffracted beams of light. The positive first-order beam focuses at a point closer to polarizing hologram 54 than photodiode 56 and the negative first-order beam focuses at a point farther than photodiode 57. Polarizing hologram 54 is configured to prevent a 0th-order beam of light from focusing on photodiode 55. As such, positive and negative first-order beams of light on photodiodes 56 and 57 form spots of light different in diameter and accordingly photodiodes 56 and 57 are adapted to have different sizes to accurately obtain a focus error signal. Photodiodes 56 and 57 are divided in a direction perpendicular to the direction in which they are arranged, into three photodiodes 56a-56c and three photodiodes 57a-57c, respectively. Photodiode 55 is divided in the same direction as that in which photodiodes 56 and 57 are arranged, into photodiodes 55a and 55b.

The second magneto-optical pickup device generally operates, as the first magneto-optical pickup device does.

In the above configuration, magneto-optical signal RF is represented by the following equation:

$$RF = (55a+55b) - \{(56a+56b+56c) + (57a+57b+57c)\} \quad \ldots (4).$$

Furthermore, focus error signal FE and tracking error signal TE are represented by the following equations (5) and (6), respectively:

$$FE = (56a+56c+57b) - (56b+57a+57c) \quad \ldots (5)$$

$$TE = 55a - 55b \quad \ldots (6).$$

Thus the second magneto-optical pickup device, as well as the first magneto-optical pickup device, can provide a sufficient S/N ratio of a magneto-optical signal and it can provide a highly reliable and durable, miniaturized and inexpensive magneto-optical pickup device. Furthermore, it does not have an excessive optical branching element such as a diffraction grating, except for polarizing prism 43, in an optical path extending from laser diode 37 to magneto-optical recording medium 12. Thus, light can be utilized more efficiently. In addition, magneto-optical signal RF, focus error signal FE and tracking error signal TE can be detected by common photodiodes 55-57 and substrate 36 can thus have a reduced photodiode area. Thus the magneto-optical pickup device can further be miniaturized and also produced at a further reduced cost.

The first magneto-optical disk pickup device, however, has hologram diffraction element 42 arranged between laser diode 37 and magneto-optical recording medium 12. As such, light diffracts and magneto-optical recording medium 12 thus receives reduced power of light. As such, the output of laser diode 37 must be increased.

Furthermore, when light output from laser diode 37 and diffracted by hologram diffraction element 42 is incident on objective lens 45, the incident light is reflected by magneto-optical recording medium 12 and projected on photodiodes 38 and 39. Thus a false signal would be introduced in a focusing error signal and a tracking error signal. This problem can be resolved simply by limiting the area in which hologram diffraction element 42 is to be formed, as in the optical pickup device disclosed in Japanese Patent Laying-Open No. 2-273336 (Japanese Patent Publication No. 7-3703), although if light is reduced in wavelength, hologram diffraction element 42 would have a grating proportionally reduced in pitch and thus the magneto-optical disk pickup device can hardly be fabricated at low cost.

Furthermore, photodiodes 38 and 39 are arranged in a vicinity of laser diode 37. As such, light emanating from laser diode 37 that is reflected by optically transparent substrate 41 tends to be incident on photodiodes 38 and 39 and thus generate a false servo signal.

Furthermore, polarization prism 43 has a width of two to five millimeters because of a condition of its arrangement and production. Accordingly between photodiodes 38 and 40 there is also provided a distance of two to five millimeters and to provide photodiodes 38-40 on the substrate, substrate 36 is required to have a size two to five times a typical substrate. This disadvantageously increases the cost for fabricating the magneto-optical disk pickup device.

In contrast, the second magneto-optical disk pickup device does not have hologram diffraction element 42 existing on the optical path extending from laser diode 37 to magneto-optical recording medium 12, as shown in Fig. 11. Thus, light does not diffract and magneto-optical recording medium 12 thus does not receive power of light reduced as in the first magneto-optical disk pickup device. The second magneto-optical disk pickup device can also be free of a false signal otherwise generated in focus and tracking error signals.

Furthermore, the second magneto-optical disk pickup device has photodiodes 55-57 arranged distant from laser diode 37 and it can thus also be free of a false servo signal otherwise generated, as in the first magneto-optical pickup device.

However, the second magneto-optical disk pickup device also has photodiodes 55-57 arranged on substrate 36. As such it requires substrate 36 having a size two to five times a typical substrate and its production cost is also disadvantageously increased.

Furthermore the second magneto-optical disk pickup device includes polarizing prism 43 formed of a large number of members. Thus, light beams incident on photodiodes 55-57 are positionally offset significantly, which makes fabrication difficult. Furthermore the yield of polarizing prism 43 is also decreased.

Furthermore, polarizing prism 43 have a plane 43a dividing light into polarized beams and a reflection plane 43b that are formed of different members. Thus its collimation can hardly be ensured with high precision and it is not suitable for mass production.

Furthermore, polarizing hologram 54 formed of lithium niobate

provides a diffraction efficiency of at most 40% for ± 1st-order diffracted beams of light and there thus exists a difference in intensity of 1.2 times between linear polarization output as 0th-order light and that output as ± 1st-order diffracted light. Thus it is difficult to calculate a differential signal as it is, to reproduce a magneto-optical signal, and in addition thereto, because of an error introduced in fabricating the hologram, polarized light that should be output as 0th-order light is partially diffracted and light that should be output as ± 1st-order diffracted light is not diffracted and instead output as 0th-order light, and a sufficient extinction ratio cannot be obtained and signal quality is impaired.

The present invention is made to overcome the disadvantages described above and it contemplates a miniaturized optical pickup device.

It also contemplates an optical pickup device capable of utilizing light efficiently.

The present invention also contemplates an optical pickup device providing an increased degree of freedom in design.

The present invention also contemplates an optical pickup device which is significantly suitable for mass production and can be fabricated with high working precision.

Disclosure of the Invention

The present invention in one aspect provides an optical pickup device including: a source of light; a lens arranged on an optical path extending from the source of light to a magneto-optical recording medium; a beam splitter arranged on an optical path extending from the source of light to the lens, to separate a portion of light reflected by the magneto-optical recording medium; and a photodetector detecting the light reflected separated by the beam splitter. The beam splitter includes: a first member made of isotropic optical material, reflecting light received from the source of light and directing the light to the photodetector, and passing a reflection of light received from the magneto-optical recording medium; and a second member adjacent to the first member, made of anisotropic optical material and further passing light reflected from the magneto-optical recording

medium past the first member.

A beam splitter formed simply of two members (first and second members) can branch reflected light and divide light into polarized beams. Thus the device can be miniaturized. Furthermore, the beam splitter formed of a small number of components can be free of significant fabrication errors and the photodetector can receive a beam of light without significant positional displacement. Thus the device can readily be fabricated. Furthermore, light can be divided into polarized beams through birefringence in crystal. Thus two separate, linearly polarized beams do not have a difference in intensity. Furthermore, an extension ratio is determined by crystallinity, and using good crystal allows an extension ratio of approximately 1:100 to be readily obtained. Thus, light can be utilized more efficiently. Furthermore, the substrate of the photodetector does not require a laser diode (LD) mounting portion. Thus the device can be miniaturized and its fabrication cost can thus be reduced.

Preferably the first member has an index of refraction substantially equal to an extraordinary index of refraction of the second member.

Selecting the first and second members to allow the first member to have an index of refraction substantially equal to an extraordinary index of refraction of the second member formed of anisotropic optical material, can increase an angle of division of light into polarized beams through a plane at which the first and second members contact each other. Thus, the first and second members can be reduced in height. Furthermore, an effect of walk-off can be reduced and the device can thus be optically readily be designed.

More preferably, the first member has an index of refraction having a difference from an extraordinary index of refraction of the second member that is no more than one half a difference between an ordinary index of refraction and the extraordinary index of refraction of the second member.

Selecting the first and second members to provide the index of refraction as above, can increase an angle of division of light into polarized beams through a plane at which the first and second members contact each other. Thus the first and second members can be reduced in height. Furthermore, although an effect of walk-off is more or less observed, the

device can be optically relatively readily designed.

More preferably, the first member is a prism having a parallelogramic cross section and having first parallel planes opposite each other and second parallel planes opposite each other and each traversing the first parallel plane at a predetermined angle, one of the first parallel planes being arranged in contact with the second member, one of the second parallel planes being arranged opposite the source of light, the other of the second parallel planes being arranged opposite the lens, and the predetermined angle is so selected that light output from the source of light and incident on one of the second parallel planes at a predetermined angle of incidence, is reflected initially by the other first parallel plane and then by one of the first parallel planes and emerges from the other second parallel plane.

The first member as seen in cross section is a parallelogram. Thus, light incident on the first member and that emerging from the first member can each be controlled to be collimated and spaced with high precision. With the first member provided in a parallelogram, the beam splitter can be fabricated by stacking a large substrate and then cutting it. This can enhance the mass-productivity of the optical pickup device.

More preferably, the second member has a crystal axis selected to be orthogonal to light emerging from the other one of the second parallel planes and to form approximately 45° to a plane including a vector in a direction of the light emerging from the other one of the second parallel planes and a vector normal to the one of the first parallel planes.

The second member of anisotropic optical material has a crystal axis selected to be orthogonal to light emerging from the other one of the second parallel planes and to form approximately 45° to a plane including a vector in a direction of the light emerging from the other one of the second parallel planes and a vector normal to the one of the first parallel planes. This allows reliable separation of a magneto-optical signal included in light condensed on a magneto-optical recording medium by the collimator lens and the objective lens.

More preferably, the optical pickup device further includes: an

optically transparent substrate arranged between the source of light and the photodetector, and the beam splitter; and a first diffraction element arranged in the optically transparent substrate at a position to receive light reflected from the magneto-optical recording medium.

Furthermore, the first diffraction element does not exist on an optical path extending from the semiconductor laser to the magneto-optical recording medium. As such, light output from the semiconductor laser can be transmitted to the magneto-optical recording medium efficiently and semiconductor laser of lower output can thus be used as the semiconductor laser. Thus the device can be miniaturized and designed with an enhanced degree of freedom and its mass-productivity can be enhanced. Furthermore, the absence of the first diffraction element on the optical path from the semiconductor laser to the magneto-optical recording medium, can eliminate the necessity of preventing light diffracted by the first diffraction element from being incident on the lens. Thus the first diffraction element can be designed with an increased degree of freedom. Furthermore, the first diffraction element may provide a small angle of diffraction and if the wavelength of incident light is reduced it is possible to maintain a large pitch of the grating of the hologram. As such, contact-printing or any other similar technique can for example be used to fabricate the first diffraction element, and the mass productivity and the working precision can be enhanced and the optical pickup device can thus be fabricated at low cost. Furthermore, the device can advantageously be free of a false signal otherwise introduced in a focus error signal and a tracking error signal as light diffracted by the first diffraction element is reflected by the magneto-optical recording medium and incident on the photodetector.

More preferably the optical pickup device further includes a second diffraction element arranged in the optically transparent substrate at a position to receive light output from the source of light, to divide the light received from the source of light into at least three beams of light.

The second diffraction element is also provided on the optically transparent substrate provided with the first diffraction element. Thus with a small number of components a reliable 3-beam system can be used to

obtain a tracking signal. Thus the device can be miniaturized and light can be utilized more efficiently.

More preferably the first and second diffraction elements are juxtaposed on a single plane.

The second diffraction element that is provided in the same plane as the first diffraction element can be fabricated simultaneously with the first diffraction element. Thus the number of fabrication steps can be reduced and the device's mass productivity can be enhanced.

More preferably the optical pickup device further includes a 1/2 wave plate arranged between the source of light and the beam splitter.

A 1/2 wave plate arranged between the source of light and the beam splitter. Thus the device can be configured regardless of the far field pattern of the source of light and the direction of polarization and also have a polarizing film readily formed at a boundary of the first and second members of the beam splitter.

More preferably, the second member has an index of refraction of 1.4 to 2.0.

Furthermore, the second member is formed of a material having an index of refraction closer to that of glass. This can reduce the angle of refraction of a main beam of light moving through a boundary of the first and second members and thus reduce astigmatism and coma introduced.

More preferably, the second member is formed of lithium tetraborate.

Forming the second member of lithium tetraborate providing a large birefringence, allows an increased spatial distance of polarized, separate beams of light.

Brief Description of the Drawings

Fig. 1 is a side view of a configuration of an optical pickup device of a first embodiment of the present invention.

Fig. 2 shows an appearance of a second diffraction element 5.

Fig. 3 illustrates a variation in rotatability of a plane of polarization of a beam of light between before and after it moves past a first plane 18.

Fig. 4 is a view for illustrating a geometry of a first diffraction element 6 and six beams of light incident on the first diffraction element 6.

Fig. 5 is a view for illustrating a geometry of a photodetector 7 and a beam of light incident on photodetector 7.

Fig. 6 is a side view of a configuration of an optical pickup device of a second embodiment of the present invention.

Fig. 7 is a view of a second diffraction element 25.

Fig. 8 is a view for illustrating a geometry of a first diffraction element 26 and six beams of light incident on the first diffraction element 26.

Fig. 9 is a view for illustrating a geometry of a photodetector 27 and a beam of light incident on photodetector 27.

Fig. 10 is a top view of a beam splitter 2 for the purpose of illustrating a crystal axis of a second member 14.

Fig. 11 is a side view of a configuration of a first conventional magneto-optical pickup device.

Fig. 12 is a top view of a light receiving element, a light emitting element and an analyzer of the first conventional magneto-optical pickup device.

Fig. 13 is a side view of a configuration of a second conventional magneto-optical pickup device.

Fig. 14 is a top view of a light receiving element and a light emitting element of the second conventional magneto-optical pickup device.

Best Mode for Implementing the Invention

First Embodiment

With reference to Fig. 1, an optical pickup device of a first embodiment of the present invention includes a stem 8, a semiconductor laser 1 arranged on stem 8 and serving as a light source, a cap 9 covering stem 8, an optically transparent substrate 4 attached on cap 9, a $1/2$ wave plate 3 attached on optically transparent substrate 4, a beam splitter 2 attached on $1/2$ wave plate 3, a collimator lens 10 and an objective lens 11 receiving light output from semiconductor laser 1 and condensing the light

on a magneto-optical recording medium 12, and a photodetector 7 arranged on stem 8 to detect light reflected by magneto-optical recording medium 12 and branched by beam splitter 2.

Beam splitter 2 is arranged on an optical path extending from semiconductor laser 1 to collimator lens 10 and separates a portion of light reflected by magneto-optical recording medium 12, as has been described above. Beam splitter 2 is formed of a first member 15 of isotropic optical material and a second member 14 of anisotropic optical material. Light from semiconductor laser 1 moves only past the first member 15 and arrives at collimator lens 10 and light reflected by magneto-optical recording medium 12 moves past the first and second members 15 and 14 and thus arrives at photodetector 7. The first member 15 is generally a prism having a parallelogramic cross section and has a first plane 18 in contact with the second member 14, a second plane 16 adjacent to the first plane 18, a third plane 17 opposite the first plane 18, and a fourth plane 19 opposite the second plane 16, and the first to fourth planes 18, 16, 17, 19 are orthogonal to a plane X-Y.

Optically transparent substrate 4 is provided with a first diffraction element 6 arranged on an optical path extending from beam splitter 2 to photodetector 7, to receive light reflected by magneto-optical recording medium 12 and partially diffract it to generate a control signal. On a plane with the first diffraction element 6 thereon at a portion passing the light output from semiconductor laser 1 is formed a second diffraction element 5 dividing the light of semiconductor laser 1 into two tracking beams and one information reproducing beam for a total of three beams.

Cap 9 has a light transmission region with a window glass 21 attached thereto and it has an interior hermetically sealed. Stem 8 and cap 9 together form a package 13, which can have an interior hermetically sealed to reliably maintain a relative, positional relationship between semiconductor laser 1 and photodetector 7.

P polarized light output from semiconductor laser 1 is divided by the second diffraction element 5 into two tracking beams and one information reproducing beam for a total of three beams. The three beams have a plane

of polarization rotated by 1/2 wave plate 3 by 90° for conversion to S polarized light. The three beams converted to S polarized light are incident on beam splitter 2 at the first member 15 through the second plane 16. The three beams incident on the first member 15 are reflected by the third and first planes 17 and 18, then output at the fourth plane 19 and then condensed by collimator lens 10 and objective lens 11 on magneto-optical recording medium 12. The second diffraction element 5 is provided on the same plane as the first diffraction element 6 is provided, as has been described previously, and it is a linear grating having predetermined intervals, as shown in Fig. 2. Furthermore, the first plane 18 has polarization characteristics set for example to have a reflectance of 70% for S polarized light (a transmittance of 30% for S polarized light) and a reflectance of 0% for P polarized light (a transmittance of 100% for P polarized light) and 70% of the light output from semiconductor laser 1 is directed to magneto-optical recording medium 12.

Herein the second diffraction element 5 has a diffraction grating parallel to an axis x. As such, the two tracking beams and one information reproducing beam are arranged parallel to an axis z. As such, in order for magneto-optical recording medium 12 to have an information track arranged parallel to the axis z, the optical pickup device and magneto-optical recording medium 12 are arranged relatively.

Light reflected by magneto-optical recording medium 12 has a plane of polarization rotated according to the direction of magnetization recorded in magneto-optical recording medium 12. The light having a plane of polarization rotated moves past objective lens 11 and collimator lens 10 and is incident on beam splitter 2 at the first member 15 via the fourth plane 19. The light incident on the fourth plane 19 moves past the first plane 18 and is incident on the second member 14. The first plane 18 has set polarization characteristics for example of a reflectance of 70% for S polarized light (a transmittance of 30% of S polarized light) and a reflectance of 0% for P polarized light (a transmittance of 100% for P polarized light), as has been described previously. Thus, when light reflected by magneto-optical recording medium 12 moves past the first plane 18, the apparent rotatability

of the plane of polarization increases. More specifically, as shown in Fig. 3, if θ represents rotatability of a plane of polarization of reflected light before the light moves past the first plane 18, then θ' represents rotatability of a plane of polarization of reflected light after the light moves past the first plane 18, wherein $\theta' > \theta$.

Since the second member 14 is optically anisotropic, the second member 14 separates a reflection of light received from magneto-optical recording medium 12 into two orthogonal polarized components which are directed in different directions, respectively. The reflection of light that is polarized and thus separated moves past $1/2$ wave plate 3 and is incident on the first diffraction element 6 and partially diffracted thereby. Since magneto-optical recording medium 12 reflects three beams of light, the polarization and separation results in a total of six beams of light incident on the first diffraction element 6.

Reference will now be made to Fig. 4 to describe a geometry of the first diffraction element 6 and six beams of light incident thereon. A circle in a solid line and that in a broken line represent light divided into two orthogonal polarized components, respectively. The first diffraction element 6 is divided into three regions 6a-6c by a boundary DL1 parallel to plane X-Y and a boundary DL2 orthogonal to boundary DL1, each having a different grating interval. Thus, an information reproducing beam of light diffracted in region 6a is incident on the Fig. 5 photodetector 7 at a photodetection portion 7a, that diffracted in region 6b is incident on the photodetector at a photodetection portion 7b, and that diffracted in region 6c is incident on a boundary of photodetection portions 7c and 7d. Photodetection portions 7c and 7d have a common boundary parallel to plane X-Y. An information reproducing beam of light transmitted through the first diffraction element 6 as 0th-order diffracted light is incident on the photodetector at photodetection portions 7e and 7f.

Two tracking beams past the first diffraction element 6 as 0th-order diffracted light are detected by photodetection portions 7g and 7h, respectively.

Thus, by calculating a difference between signals output from

photodetection portions 7c and 7d a focus error signal can be obtained according to Foucault's law, and by calculating a difference between signals output from photodetection portions 7g and 7h a radial error signal can be obtained according to a 3-beam method. Furthermore, by calculating a difference between signals output from photodetection portions 7a and 7b a so-called push-pull signal can be obtained, which is used for example to detect an address signal recorded by a tracking groove formed to meander on magneto-optical recording medium 12. A magneto-optical signal can be obtained by calculating a difference between signals output from

photodetection portions 7e and 7f.

Preferably, beam splitter 2 has the second member 14 closer in index of reflection to the first member 15, since such allows the boundary to provide small diffraction to reduce astigmatism. If astigmatism is increased, photodetector 7 would have thereon a spot of condensed light messed and thus increased in size and photodetector 7 is required to have an accordingly increased size, disadvantageously. The first member 15 is typically formed of glass, with an index of refraction of 1.4 to 2.0. As such, desirably the second member 14 has an index of refraction of 1.4 to 2.0 and preferably it is formed of crystal (Ne = 1.547, No = 1.539), sapphire (Ne = 1.760, No = 1.768) or lithium tetraborate (Ne = 1.605, No = 1.549). Note that Ne represents an index of refraction in birefringence for an extraordinary ray and No represents an index of refraction in birefringence for an ordinary ray. In particular, lithium tetraborate provides large birefringence and can thus spatially separate two polarizations with a small distance. This is preferable as package 13 can be reduced in size.

The 1/2 wave plate 3 may be dispensed with, although preferably it should be arranged; the device will be more readily fabricated if a polarizing film formed on the first plane 18 of the member 15 of beam splitter 2 has a reflectance generally higher for S polarized light, and if semiconductor laser 1 outputs light having a direction of polarization corresponding to P polarized light the direction of polarization is rotated by 1/2 wave plate 3 by 90°.

The optical pickup device as described above can branch reflected light and divide light into polarized beams by means of beam splitter 2 configured simply by two members (the first and second members 15 and 14). Thus the device can be miniaturized. Since beam splitter 2 can be formed of a small number of components it can be free of significant fabricating errors and photodetector 7 can receive a beam of light without significant positional displacement. Thus the device can readily be fabricated. Furthermore, light is divided into polarized beams through birefringence in crystal. As such, two separate, linear polarizations do not have a difference in intensity. Since an extension ratio is determined by crystallinity, using

a good crystal can readily provide an extension ratio of approximately 1:100 and hence a high light utilization efficiency. Furthermore, photodetector 7 does not require a portion for mounting an LD thereon and the substrate can thus be reduced in size and the production cost can accordingly be reduced.

Furthermore, the first member 15 has a parallelogramic cross section and light incident on the first member 15 and that emanating therefrom can each be controlled to be collimated and spaced with high precision. Since the first member 15 is a parallelogram, beam splitter 2 can be fabricated by stacking a large substrate and then cutting it. This can enhance the mass-productivity of the optical pickup device.

Furthermore, the first diffraction element 6 does not exist on an optical path extending from semiconductor laser 1 to magneto-optical recording medium 12. As such, light output from semiconductor laser 1 can be transmitted to magneto-optical recording medium 12 efficiently and semiconductor laser of lower output can thus be used as semiconductor laser 1. Thus the device can be miniaturized and designed with an enhanced degree of freedom and its mass-productivity can be enhanced. Furthermore, the absence of the first diffraction element 6 on the optical path from semiconductor laser 1 to magneto-optical recording medium 12, can eliminate the necessity of preventing light diffracted by the first diffraction element 6 from being incident on collimator lens 10 and objective lens 11. Thus the first diffraction element 6 can be designed with an increased degree of freedom. Furthermore, the first diffraction element 6 may provide a small angle of diffraction and if the wavelength of incident light is reduced it is possible to maintain a large pitch of the grating of the hologram. As such, contact-printing or any other similar method can for example be used to fabricate the first diffraction element 6, and the mass productivity and the working precision can be enhanced and the optical pickup device can thus be fabricated at low cost. Furthermore, the device can advantageously be free of a false signal otherwise introduced in a focus error signal and a tracking error signal as light diffracted by the first diffraction element 6 is reflected by magneto-optical recording medium 12 and incident on photodetector 7.

Furthermore, the second diffraction element 5 is also provided on optically transparent substrate 4 provided with the first diffraction element 6. Thus with a small number of components a reliable 3-beam system can be used to obtain a tracking signal. Thus the device can be miniaturized and light can be utilized more efficiently. Furthermore, the second diffraction element 5 that is provided in the same plane as the first diffraction element 6 can be fabricated simultaneously with the first diffraction element 6. Thus the number of fabrication steps can be reduced and the device's mass productivity can be enhanced.

Furthermore, 1/2 wave plate 3 is arranged between beam splitter 2 and package 13. Thus, the pickup can be configured regardless of the per field pattern of semiconductor laser 1 and the direction of polarization and a polarizing film formed on beam splitter 2 at the first plane 18 can also readily be formed.

Furthermore, the second member 14 is formed of a material having an index of refraction closer to that of glass. This can reduce the angle of refraction of a main beam of light moving through a boundary of the first and second members 15 and 14 and thus reduce astigmatism and coma introduced.

Forming the second member 14 of lithium tetraborate providing a large birefringence, allows an increased spatial distance of polarized, separate beams of light.

Second Embodiment

With reference to Fig. 6, an optical pickup device of a second embodiment of the present invention includes a stem 8, a semiconductor laser 1 arranged on stem 8 and serving as a light source, a cap 9 covering stem 8, an optically transparent substrate 4 attached on cap 9, a beam splitter 2 attached on 1/2 wave plate 3, a collimator lens 10 and an objective lens 11 receiving light output from semiconductor laser 1 and condensing the light on a magneto-optical recording medium 12, and a photodetector 27 arranged on stem 8 to detect light reflected by magneto-optical recording medium 12 and branched by beam splitter 2.

Beam splitter 2 is arranged on an optical path extending from

semiconductor laser 1 to collimator lens 10 and separates a portion of light reflected by magneto-optical recording medium 12, as has been described above. Beam splitter 2 is formed of a first member 15 of isotropic optical material and a second member 14 of anisotropic optical material. Light from semiconductor laser 1 moves only past the first member 15 and arrives at collimator lens 10 and light reflected by magneto-optical recording medium 12 moves past the first and second members 15 and 14 and thus arrives at photodetector 27. The first member 15 is generally a prism having a parallelogramic cross section and has a first plane 18 in contact with the second member 14, a second plane 16 adjacent to the first plane 18, a third plane 17 opposite the first plane 18, and a fourth plane 19 opposite the second plane 16.

Optically transparent substrate 4 is provided with a first diffraction element 6 arranged on an optical path extending from beam splitter 2 to photodetector 27, to receive light reflected by magneto-optical recording medium 12 and partially diffract it to generate a control signal. On a plane with the first diffraction element 26 thereon at a portion passing the light output from semiconductor laser 1 is formed a second diffraction element 25 dividing the light of semiconductor laser 1 into two tracking beams and one information reproducing beam for a total of three beams.

Cap 9 has a light transmission region with a window glass 21 attached thereto and it has an interior hermetically sealed. Stem 8 and cap 9 together form a package 23, which can have an interior hermetically sealed to reliably maintain a relative, positional relationship between semiconductor laser 1 and photodetector 27.

S polarized light output from semiconductor laser 1 is divided by the second diffraction element 25 into two tracking beams and one information reproducing beam for a total of three beams. The three beams are incident on beam splitter 2 at the first member 15 through the second plane 16. The three beams incident on the first member 15 are reflected by the third and first planes 17 and 18, then output at the fourth plane 19 and then condensed by collimator lens 10 and objective lens 11 on magneto-optical recording medium 12. The second diffraction element 25 is provided on the

same plane as the first diffraction element 26 is provided, as has been described previously, and it is a linear grating having predetermined intervals, as shown in Fig. 7. Furthermore, the first plane 18 has polarization characteristics set for example to have a reflectance of 70% for S polarized light (a transmittance of 30% for S polarized light) and a reflectance of 0% for P polarized light (a transmittance of 100% for P polarized light) and 70% of the light output from semiconductor laser 1 is directed to magneto-optical recording medium 12.

Light reflected by magneto-optical recording medium 12 has a plane of polarization rotated according to the direction of magnetization recorded in magneto-optical recording medium 12. The light having a plane of polarization rotated moves past objective lens 11 and collimator lens 10 and is incident on beam splitter 2 at the first member 15 via the fourth plane 19. The light incident on the fourth plane 19 moves past the first plane 18 and is incident on the second member 14. The first plane 18 has set polarization characteristics for example of a reflectance of 70% for S polarized light (a transmittance of 30% of S polarized light) and a reflectance of 0% for P polarized light (a transmittance of 100% for P polarized light), as has been described previously. Thus, when light reflected by magneto-optical recording medium 12 moves past the first plane 18, the apparent rotatability of the plane of polarization increases.

Since the second member 14 is optically anisotropic, the second member 14 separates a reflection of light received from magneto-optical recording medium 12 into two orthogonal polarized components which are directed in different directions, respectively. The reflection of light that is polarized and thus separated is incident on the first diffraction element 26 and partially diffracted thereby. Since magneto-optical recording medium 12 reflects three beams of light, the polarization and separation results in a total of six beams of light incident on the first diffraction element 26.

Reference will now be made to Fig. 8 to describe a geometry of the first diffraction element 26 and six beams of light incident thereon. A circle in a solid line and that in a broken line represent light divided into two orthogonal polarized components, respectively. The first diffraction

element 6 has three regions 26a-26c, each having a different grating interval. Thus, an information reproducing beam of light diffracted in region 26a is incident on the Fig. 9 photodetector 27 at a photodetection portion 27a, that diffracted in region 26b is incident on the photodetector at a photodetection portion 27b, and that diffracted in region 26c is incident on a boundary of photodetection portions 27c and 27d. An information reproducing beam of light transmitted through the first diffraction element 26 as 0th-order diffracted light is incident on the photodetector at photodetection portions 27f and 27i.

Two tracking beams past the first diffraction element 26 as 0th-order diffracted light are detected by photodetection portions 27e and 27g and photodetection portions 27h and 27j, respectively.

Thus, by calculating a difference between signals output from photodetection portions 27c and 27d, a focus error signal can be obtained according to Foucault's law, and by calculating a difference between a sum of signals output from photodetection portions 27e and 27g and that of signals output from photodetection portions 27h and 27j, a radial error signal can be obtained according to a 3-beam method. Furthermore, by calculating a difference between signals output from photodetection portions 27a and 27b, a so-called push-pull signal can be obtained, which is used for example to detect an address signal recorded by a tracking groove formed to meander on magneto-optical recording medium 12. A magneto-optical signal can be obtained by calculating a difference between signals output from photodetection portions 27f and 27i.

Preferably, beam splitter 2 has the second member 14 closer in index of reflection to the first member 15, since such allows the boundary to provide small diffraction to reduce astigmatism. If astigmatism is increased, photodetector 27 would have thereon a spot of condensed light messed and thus increased in size and photodetector 27 is required to have an accordingly increased size, disadvantageously. The first member 15 is typically formed of glass, with an index of refraction of 1.4 to 2.0. As such, desirably the second member 14 has an index of refraction of 1.4 to 2.0 and preferably it is formed of crystal (Ne = 1.547, No = 1.539), sapphire (Ne =

1.760, No = 1.768) or lithium tetraborate (Ne = 1.548, No = 1.604). In particular, lithium tetraborate provides large birefringence and can thus spatially separate two polarizations with a small distance. This is preferable as package 23 can be reduced in size.

Furthermore the first member 15 of isotropic material forming beam splitter 2 is selected such that the first member 15 provides an index of refraction equivalent to an extraordinary index of refraction Ne of the second member 14 of anisotropic optical material, since such allows a large angle of division of light into polarized beams through the first plane 18. In other words, desirably the first member 15 is formed of a material having an index of refraction allowing a difference between an index of refraction of the first member 15 and extraordinary index of refraction Ne of the second member to be no more than one half of a difference between ordinary index of refraction No and extraordinary index of refraction Ne of the second member. In general, a birefringent material has an index of refraction which can be determined based on indicatrix, and defined by an orientation of a crystal axis of the birefringent material and a direction of polarization of a beam of light incident on the birefringent material.

For example, the first and second members 15 and 14 are formed of optical glass SF2 available from Schott Group (Ne = 1.63553, wherein N represents an index of refraction) and lithium tetraborate (Ne = 1.548, No = 1.604), respectively, and an angle formed by a direction of polarization of light incident on the second member 14 and a crystal axis of the second member 14 is set to be 45°. Extraordinary index of refraction Ne' of the second member 14 before the above incident light is obtained from a calculation, as appropriate, based on a relationship between the direction of polarization of light incident on the second member 14 and the crystal axis of the second member 14 and it is 1.563.

Alternatively, the first and second members 15 and 14 are formed of SF2 (N = 1.63553) and lithium tetraborate (Ne = 1.548, No = 1.604), respectively, and an angle formed by a direction of polarization of light incident on the second member 14 and a crystal axis of the second member 14 is set to be 0°. Extraordinary index of refraction Ne' of the second

member 14 for the above incident light is 1.548. Thus, depending on the angle formed by the direction of polarization of light incident on the second member 14 and the crystal axis of the second member 14, an angle of division of extraordinary light into polarized beams through a boundary of the first and second members 15 and 14 varies. This phenomenon is referred to as walk-off.

Three examples will now be provided to show that an angle of division of light into polarized beams varies for different materials used to form beam splitter 2.

In the first example, beam splitter 2 is formed of the first member 15 of a glass material of SF2 (N = 1.63553) and the second member 14 of a birefringent material of lithium tetraborate (Ne = 1.548, No = 1.604). Furthermore, when an angle formed by a direction of polarization of light incident on the second member 14 and a crystal axis of the second member 14 is set to be 45°, the walk-off is introduced. Thus an angle of division of light into polarized beams through a boundary of the first and second members, is approximately 1.597°. In this example, there is a large difference between an index or refraction of SF2 and an extraordinary index of refraction of lithium tetraborate. Furthermore, ordinary light has astigmatism larger than extraordinary light. Thus the device is optically difficult to design.

In the second example, the first member 15 is formed of a glass material having an index of refraction equivalent to extraordinary index of refraction Ne of a birefringent material serving as the second member 14. For example, the first member 15 is formed of optical glass PSK3 (N = 1.547) available from Schott Group and the second member 14 is formed of lithium tetraborate (Ne = 1.548, No = 1.604). When an angle formed by a direction of polarization of light incident on the second member 14 and a crystal axis of the second member 14 is set to be 45°, the walk-off is reduced and an angle of division of light into polarized beams through the boundary is approximately 2.001°. Thus, using a glass material having an index of refraction equivalent to the extraordinary index of refraction of the second member 14, rather than SF2 (N = 1.63553), to form the first member 15 can

increase an angle of division of light into polarized beams.

With reference to Fig. 10, the second member 14 is formed of a birefringent material having a crystal axis in a direction set to be 45° in the same plane as the fourth plane 14 relative to a line of intersection 2a of the third and fourth planes 17 and 19. This allows reliable separation of a magneto-optical signal included in light reflected by magneto-optical recording medium 12.

In the third example, a glass material is used to provide a difference between an extraordinary index of refraction of a birefringent material serving as the second member 14 and an index of refraction of a glass material serving as the first member 15 that is no more than one half of a difference between ordinary and extraordinary indexes of refraction of the second member 14. For example, the first member 15 is formed of optical glass LF5 (N = 1.5722) available from Schott Group and the second member 14 is formed of lithium tetraborate (Ne = 1.548, No = 1.604). Furthermore, when an angle formed by a direction of polarization of light incident on the second member 14 and a crystal axis of the second member 14 is set to be 45°, the walk-off is more or less introduced, although an angle of division of light into polarized beams through a boundary of the first and second members 15 and 14 is approximately 1.98°. In this example, ordinary light and extraordinary light have astigmatism of approximately the same level. Thus the device is optically readily designed.

In the optical pickup device as described above, selecting the first and second members 15 and 14 to allow the first member 15 to provide an index of refraction equivalent to an extraordinary index of refraction of the second member 14 formed of anisotropic optical material, can increase an angle of division of light into polarized beams through the first plane 18. As such, package 23 can be reduced in height and the device can thus be miniaturized. Furthermore, an effect of walk-off can be reduced and the device can thus be optically readily designed.

Furthermore, a direction of a crystal axis of the second member 14 formed of anisotropic optical material is selected to form an angle of 45° in the same plane as the fourth plane in 14 to line of intersection 2a of the third

and fourth planes 17 and 19 in fabricating beam splitter 2. This allows reliable separation of a magneto-optical signal included in light condensed on magneto-optical recording medium 12 by collimator lens 10 and objective lens 11.

Industrial Applicability

Thus the present invention can provide an optical pickup device using only two members (first and second members) to form a beam splitter to branch reflected light and divide light into polarized beams. Thus it is suitable for an optical pickup device for use in magneto-optical disk reproduction apparatuses required to be miniaturized.